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WRF-PDM: Prognostic approach for discharge prediction in ungauged catchment

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Abstract: In this study, the mesoscale model WRF (Weather Research & Forecasting model) is used for dynamical downscaling of European Centre for Medium Range Weather Forecasts (ECMWF) ERA interim reanalysis global datasets for obtaining hydro-meteorological variables. The WRF estimated precipitation and Evapo-transpiration are then used as input data for the Probability Distributed Model (PDM) for discharge prediction. For performance evaluation of the integrated framework, objective function like Nash Sutcliffe Efficiency (NSE) is used. Analysis of NSE indicates values of 0.85 and 0.82 during the calibration and validation respectively for the combination observed rainfall and station based reference Evapotranspiration (ETo). On the other hand, a marginally lower performance is reported by the combination Observed Rainfall and WRF based ETo ($NSE_{cal}=0.82;\ NSE_{val}=0.80$), while a very poor performance is reported by the combination Rainfall and ETo when both derived from WRF ($NSE_{cal}=0.58;\ NSE_{val}=0.06$). The overall analysis suggests that the WRF-PDM can be used for discharge prediction in the absence of ground based measurements. This study provides valuable information to the hydro-meteorologist on downscaled weather variables from global datasets and its applicability to rainfall-runoff modeling for river discharge prediction.

Key words: WRF-PDM, GLUE, Rainfall-runoff, Discharge, Sensitivity Analysis and Uncertainty Estimation

1. INTRODUCTION

Precipitation and Reference Evapotranspiration (ETo) are considered as two important key variables for rainfall runoff modelling (Shukla and Mintz, 1982). The WRF model is used by many researchers in last decade and found to be promising for regional applications and development of operational numerical weather prediction (Lo *et al.*, 2008; Givati *et al.*, 2011). Recently, efforts have been made to estimate ET and precipitation using Weather Research and Forecasting model (WRF) (Bukovsky and Karoly, 2009; Skok *et al.*, 2010).

Among hydrological models, the lumped rainfall runoff model PDM (Probability Distributed Model) has been widely used in many parts of the world with satisfactory performances (Srivastava *et al.*, 2013). PDM model is developed by the UK Centre for Ecology and Hydrology by Moore in (Moore, 2007). The PDM model uses long records of flow and rainfall and provides a highly effective representation of the runoff generation process (Srivastava *et al.*, 2014). Because of its high performance it is also used in this study for discharge esatimation.

In purview of the above, the main aim of this study is to examine the performance of WRF-PDM framework for discharge prediction with different input data conditions derived from global reanalysis datasets using WRF and station based measurements. This type of study is important to understand the model performances and their suitability for discharge prediction especially for ungauged catchments.

2. MATERIALS AND METHODOLOGY

The Brue catchment is located in the south-west of England and used as a case study in this work. The flow and rainfall datasets are provided by Environment agency, UK, while meteorological datasets are provided by the British Atmospheric Data Centre *(*BADC), UK. The hourly datasets from August 2010 to January 2012 are used for calibration and validation of the model. The global European Centre for Medium Range Weather Forecasts (ECMWF) ERA interim reanalysis data is used as forcing for Weather Research and Forecasting (WRF) model (http://www.ecmwf.int/). The latest WRF model is used in this study with the Advanced Research WRF (ARW) dynamic core (Powers, 2007; Schwartz *et al.*, 2009). The WRF model is centered over the Brue catchment with three nested domains (D1, D2 and D3). The innermost high resolution domain (D3) is used in this study. The outputs of WRF i.e. precipitation and ET are used as inputs in the lumped rainfall runoff model PDM (Probability Distributed Model) for discharge prediction. Total five PDM parameters - C_{max} (maximum store capacity), b (exponent of pareto distribution), g (groundwater recharge time constant), K_f (fast flow component) and K_s (slow flow component) are used for model calibration.

3. RESULTS AND DISCUSSION

The WRF estimated precipitation and ETo are used as input for the Probability Distributed Model (PDM) for discharge prediction. Total three input data conditions are designed for assessing the WRF-PDM performance for discharge prediction as shown in Table 1.

Table 1. Different combinations used in this study

S.No.	Input conditions	Combinations
1	Set1	Observed Rainfall and Station based ETo
2	Set2	Observed Rainfall and WRF based ETo
3	Set3	Rainfall and ETo both from WRF

Sensitivity analysis is performed on the locally conditioned PDM model parameters C_{max}, b, g, K_f and K_s. After optimizing the PDM model parameters, the discharge by using the different combinations are estimated and the hydrographs are presented in Fig. 1.

The performance is depicted in terms of Taylor diagram as shown in Fig. 2. It provides a simpler way of presenting the model performances using the graphical interface by summarizing how closely the model simulated results match with the observations. The performances between the two datasets are quantified in terms of their correlation, their centered root-mean-square difference and the standard deviations. In calibration, poorest performance can be seen in case of set3, while set1 and set2 are mostly similar in prediction discharge. During the validation, the worst performance is reported by set3 and better in case of set1 and set2.

The analysis of objective function Nash Sutcliffe Efficiency (NSE) indicates values of 0.85 and 0.82 during the calibration and validation respectively (set-1). On the other hand, a marginally lower performance are reported by set-2 (NSE_{cal}= 0.82; NSE_{val}= 0.80), while a very poor performance is reported by set-3 (NSE_{cal}= 0.58; NSE_{val}= 0.06). The lower performance of set3 can be attributed to the poor simulation of WRF precipitation, which indicates that more work is needed on improvement of parameterization schemes for discharge prediction.

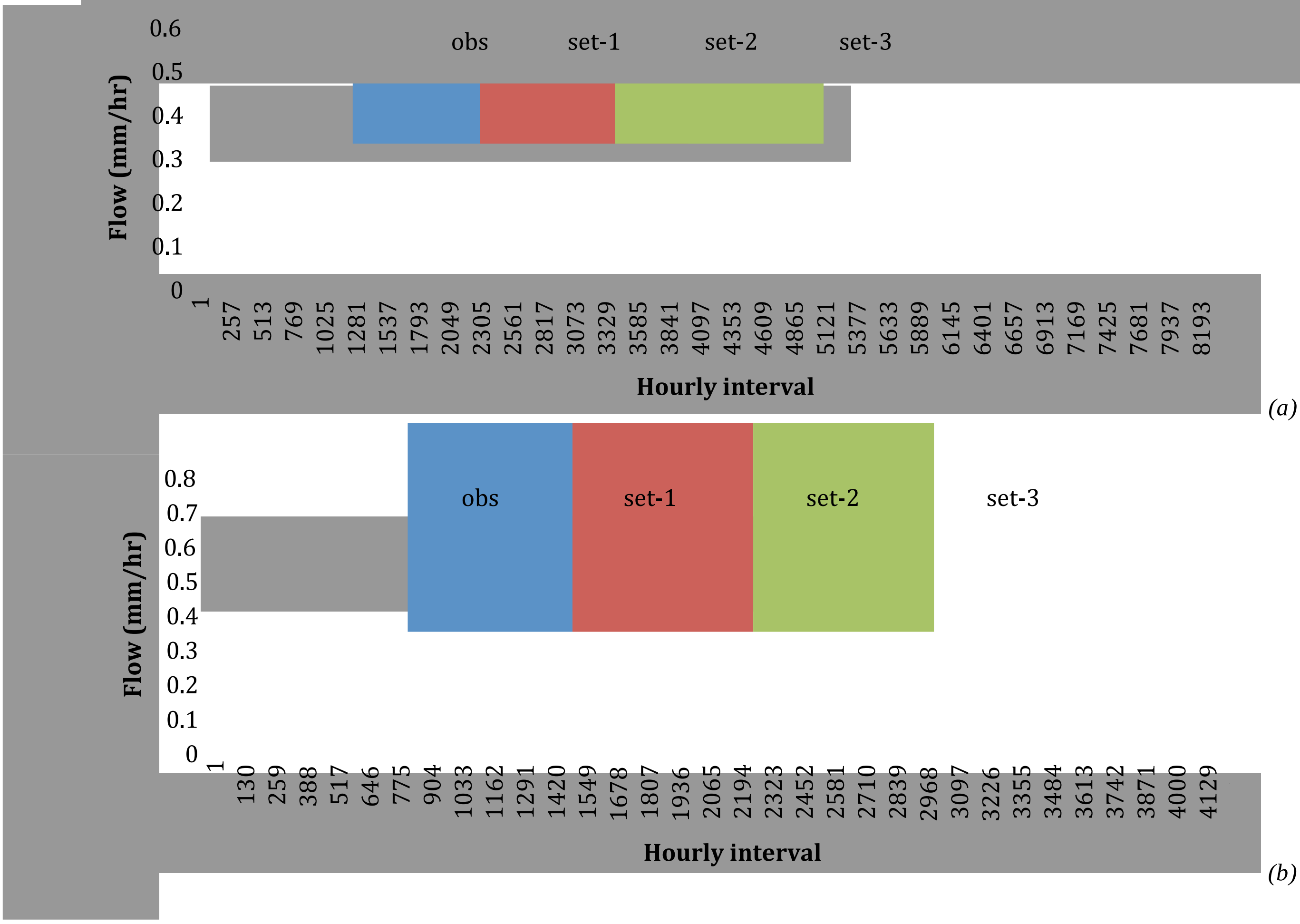

Figure 1. Hydrographs obtained by using different combinations: (a) Calibration; (b) Validation

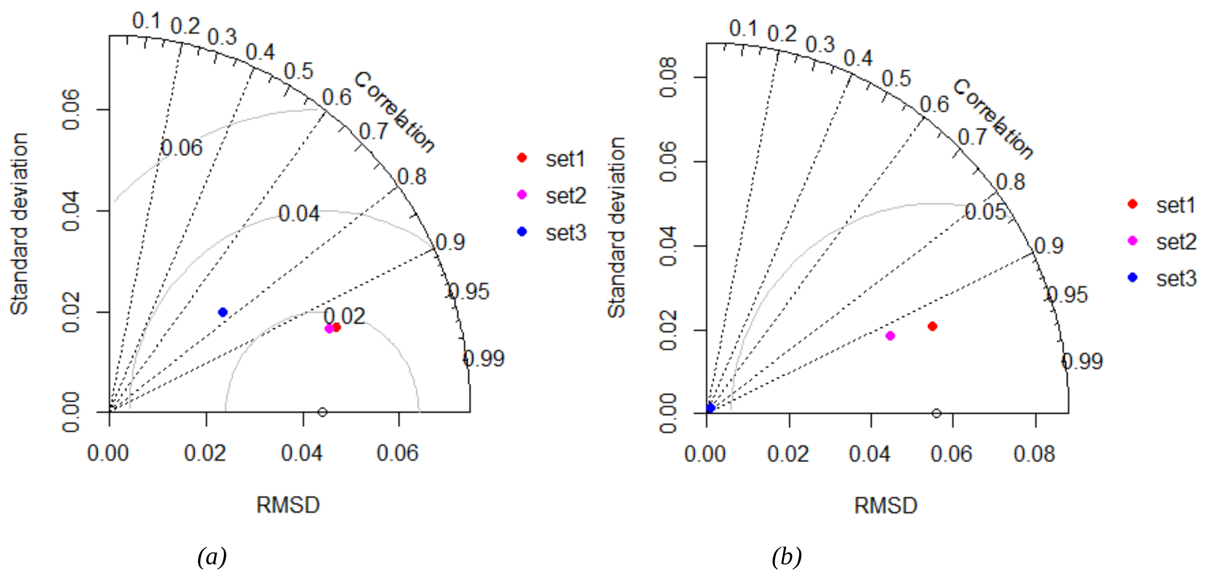

Figure 2. Taylor diagram showing the performance of different combinations: (a) Calibration; (b) Validation

The overall analysis suggests that the estimates in the predicted discharge using the WRF derived ET have comparable performance with the ground based observed datasets and hence promising for the discharge prediction in the absence of ground based measurements of ET.

4. CONCLUSIONS

The over application of WRF indicates that it is able to downscale the global data into much finer resolutions in space and time for hydro-meteorological applications. Further, it can be used in integration with PDM model for prediction of discharge. The different datasets used in this study indicates that the WRF downscaled meteorological variables can be used for ET. Further the quality of ET derived is better than the WRF simulated precipitation, which is also reflected by the simulated discharge. The overall analysis indicates that the WRF precipitation is least useful for discharge prediction and therefore better schemes or forcing are needed for precipitation. On the other hand, ET is giving satisfactory performance, when used with observed rainfall. This study can provide hydrologists with valuable information on downscaled weather variables from global datasets and its applicability for rainfall-runoff modeling.

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